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WELD FRACTURE CRITERIA FOR COMPUTER SIMULATION

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Introduction

Due to the complexity of welding, not all of the important factors are always properly considered and controlled. An automatic system is required. This report outlines a simulation method and all the important considerations to do this. As in many situations where a defect or failure has occurred, it is frequently necessary to trouble shoot the system and eventually identify those factors that were neglected. This is expensive and time consuming. Very frequently the causes are materials-related that might have been anticipated. Computer simulation can automatically consider all important variables. The major goal of this presentation is to identify the proper relationship of design, processing and materials variables to welding.

Welding

An arc welded structure is usually described in terms of a fusion zone, a heat affected zone (HAZ) and the base metal. The properties of the fusion zone are dominated by details of the solidification process and the HAZ is a modification of the base metal by prolonged exposure to elevated temperatures. Welding also produces changes in geometry that are manifest in visible features.

There are three stages in the simulation. The first stage is to determine the geometry of the welded structure, which is based on the welder's input of part thickness, welding power and speed. Residual stress is also a significant factor in welding and must be computed. The simulationist, who must also understand welding, sets the parameters for arc efficiency, partitioning between point and line source and physical properties of the system. A grid is assigned to the weld in the first stage and is followed throughout the simulation. Figure 1 illustrates the shape of the weld bar and its regions of microstructure.

The goal of the second stage operations is to assign a flow curve to each element. This involves the simulation of microstructure and properties. The width and geometry of the fusion zone and the determination of temperature gradient in the liquid lead to a specification of property controlling features. The changes in the HAZ are computed from thermal exposures.

The final stage is the determination of fracture details. Each step is based on the concept that the response of each element in the structure is governed, solely, by its condition and loading. The program uses object oriented programming methods, see Booch (1). Thus, the simulation of weld structure is planned for a number of source code classes in a library organized into objects that define shape, regional structure, operational parameters and microstructural parameters. The simulation third stage uses these objects to reach the final result.

Weld Structure

Weld structure is established by simulating the geometry of the weld pool. The equilibrium phase diagram and other materials-specific reference tools provide information about melting point, freezing range, chemical partitioning and solubility. The principal operating parameter is the energy input which is the ratio of total input power to welding speed. Easterling (3) describes the thermal distribution in welding which is characterized by the flow of heat away from a moving source. The governing equation is equation 2. Equations (1) and (2) define the information that must be provided.

$$q = \eta \ E \ I \qquad [1]$$

Where q is the total input power
η is the arc efficiency
E is the arc voltage
and I the beam current.,

The boundary conditions for integrating equation (2) are based on the geometry of the base metal.

$$\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = -2\lambda v \frac{\partial T}{\partial X} \qquad [2]$$

Where X, y and z are a Cartesian coordinate system fixed to the motion of the arc along X,
T is the absolute temperature
λ is the thermal conductivity
and v is the heat capacity.

The size of the reinforcement depends on the base metal preparation, distortion during welding, width of the fusion zone and amount of filler added.

Flow Curve

The key parameters of the flow curve are the elastic slope, the strain hardening exponent, and coordinates of the UTS and breaking point. Each of the latter parameters on processing. Cottrell (2) reviews the governing principles. The results of a tensile test can be presented as an engineering stress-strain curve.

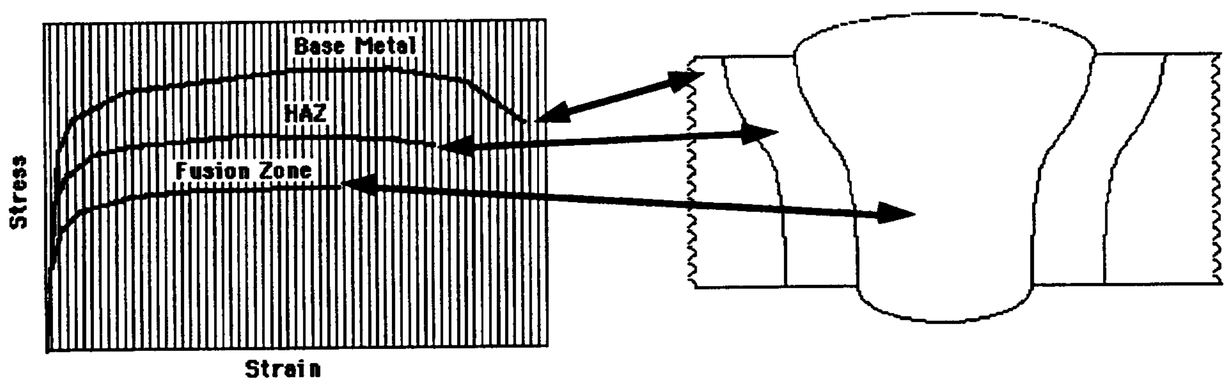

Figure 1. Stress-strain curves of typical parts of the welded structure.

The flow curve is different at each point as shown in Figure 1. The base metal has the optimum values of strength and ductility since it has been heat treated to the optimum prior to welding. The alloy in the fusion zone is completely changed with the development of a dendritic structure. The HAZ is that part of the unmelted base metal that has been subjected to elevated temperatures for enough time to allow changes. Each process is represented by one or more governing relations which are used to adjust the features of the flow curve.

The stress on an element varies inversely with section area. The initial deformation is elastic. As the loading increases, the stress is reached where significant plastic flow occurs, represented by the strain hardening exponent. At higher levels of deformation vacancy production becomes important. This counteracts and limits work hardening, resulting in the UTS that is a prominent part of engineering stress-strain curves. Each parameter of the flow curve is considered separately.

Properties

The mechanical test is simulated in incremental steps of sample extension as shown by the strain increments in figure 1. Every element is evaluated at each step. The calculated stress is compared with the failure stress of each element. Eventually there will be an element that is the first to reach its failure stress and this will be marked for the point of fracture initiation. The sequence and positions of the other elements that fail will also be recorded to describe the shape of the failure surface. The overall extent of sample elongation determines weld ductility.

Conclusions

The integrated weld simulation system is planned to provide information about welding with a specified alloy that is equivalent to actually making a weld in the shop. The proposed system includes all details of materials properties and behavior that are required in trouble shooting and are too complex to include in most specifications. The simulation is planned for speed and accuracy and produces reports with lists of results, parameters used in the simulation, and approximations that were invoked. This is more information than is usually available.

References

1. Booch, G. C., *Object Oriented Design with Applications*, The Benjamin/Cummings Publishing Co., (1991).
2. Cottrell, A. H., *The Mechanical Properties of Matter*, John Wiley & Sons., Inc., (1964).
3. Easterling, K. E., *Introduction to the Physical Metallurgy of Welding*, Butterworths & Co., (1983).